Global Navigation Satellite Systems Reflectometry (GNSS-R) Algorithms for Wetlands Observations

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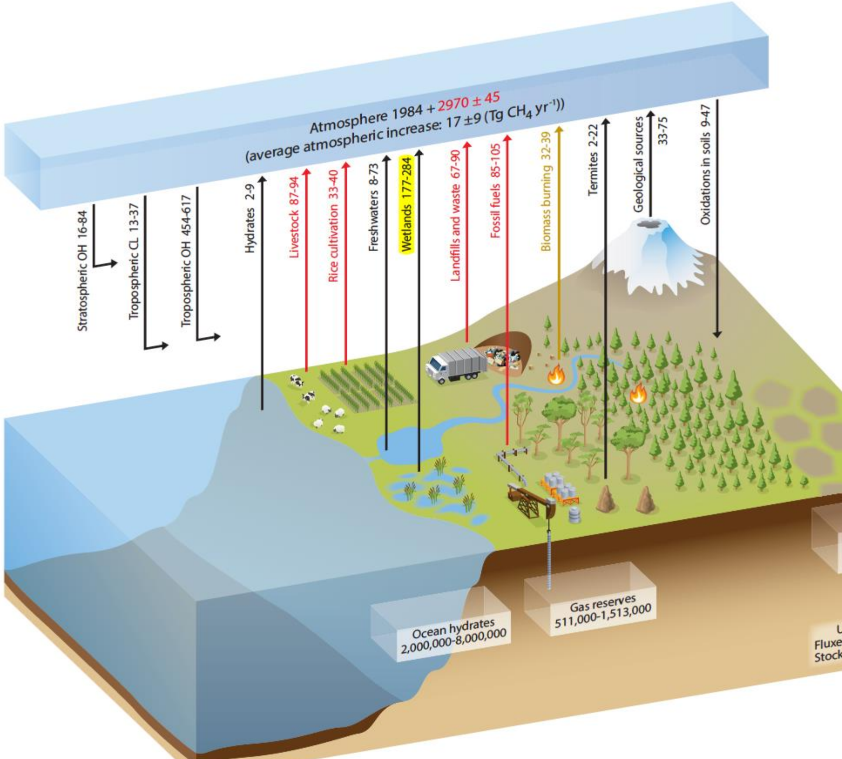
Rice fields around Pavia, Italy: Cinzia's wetlands

Outline

- Wetlands
  - Role of wetlands in hydrology and energy cycles
  - Observational needs and gaps
- GNSS-R
  - What is GNSS reflectometry and why it is suitable for wetlands detection
  - Algorithms from TDS-1, CyGNSS, SMAP
- Summary and next steps

Wetlands as Driver of Methane Emissions

- IPCC AR5 highlights the role of wetlands as a key driver of methane (CH_4) emission
  - CH_4 is one order of magnitude stronger than carbon dioxide as a greenhouse gas in the centennial time scale
- Wetlands are the largest methane emission sources (30%) with the widest uncertainty range of 177-284 $Tg(CH_4)\ yr^{-1}$
  - severely limits the confidence level of climate change projection
- Establish global wetland inventory and monitor its dynamics in days to years and at spatial scales < 1 km
- Mission to globally monitor wetlands not yet on the books; existing instruments have limitations in achieving needed spatial/temporal resolution or seeing through vegetation



Global cycle of CH_4
Fig. 6.2, *IPCC*, 2013

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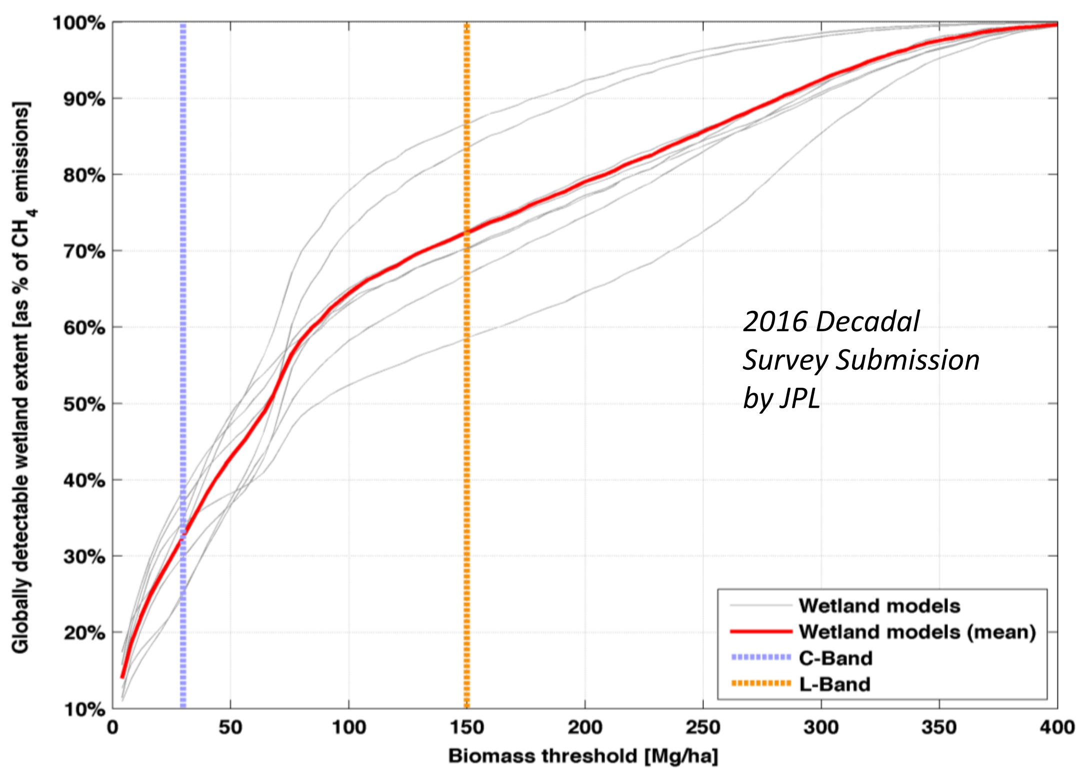
Wetlands Obstructed by Vegetation



Detecting inundation in densely vegetated areas (up to 100 Mg/ha) is necessary to observe the global wetland areas emitting the majority of global wetland CH_4

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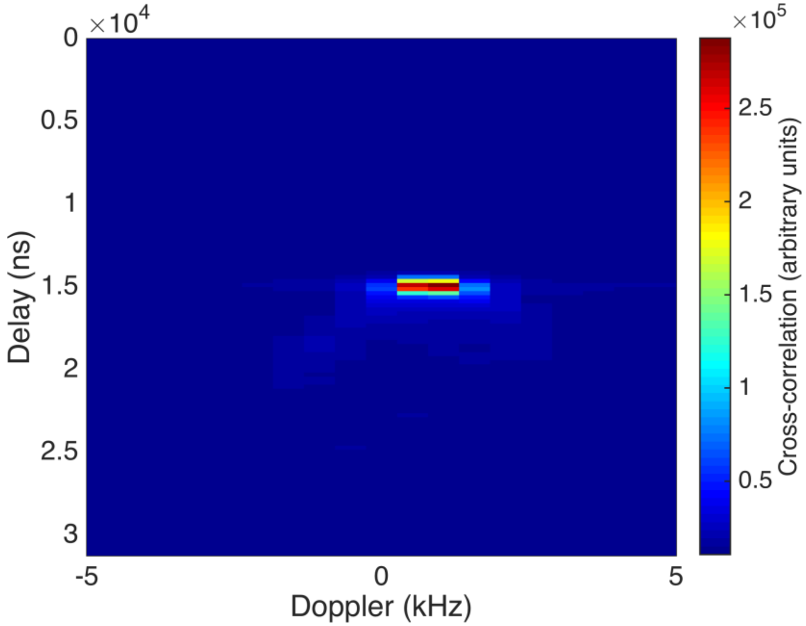
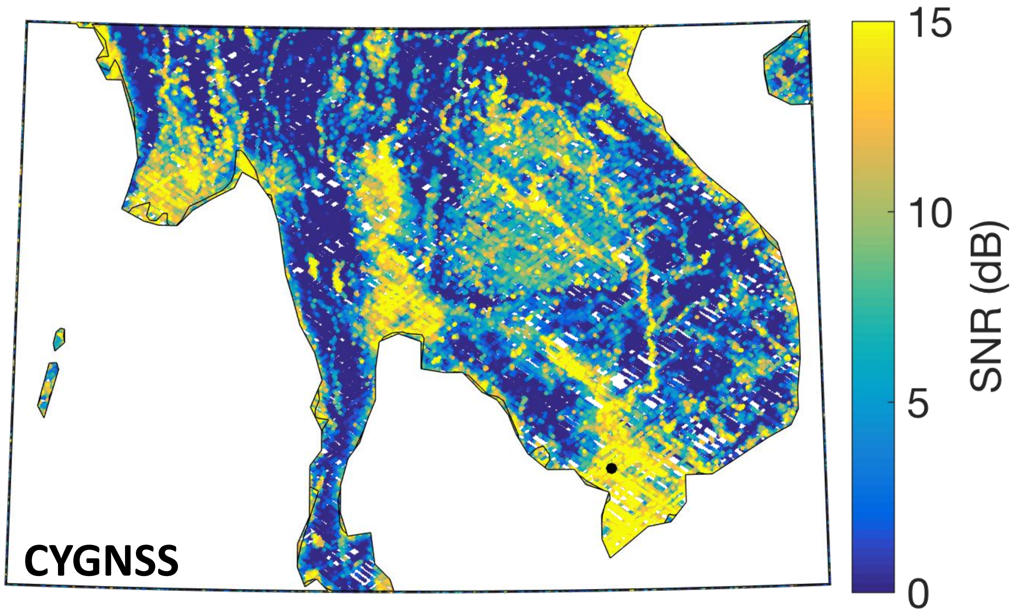
Characteristics of GNSS-R





- Bistatic radar system where GNSS constellations transmit signals that are received by user designed instruments on platforms in LEO after the signals are scattered off the Earth surfaces primarily in the forward direction
- Forward scattered signal is coherent over wetlands and can penetrate vegetation; big jump in SNR allows detection

Near Term Opportunities

- CYGNSS
  - Can observe the low latitude wetlands
  - High temporal resolution, suitable for capturing high frequency dynamics
  - Data processing not optimized for wetlands products but for wind fields; 1 sec incoherent averaging will degrade resolution
- TDS-1
  - Can observe all latitude wetlands
  - Data processing not optimized for wetlands products; 1 sec incoherent averaging will degrade resolution
- SMAP (GNSS-R mode)
  - Can observe all latitude wetlands
  - Data processing can be customized to increase spatial resolution
  - Not optimized for GNSS-R

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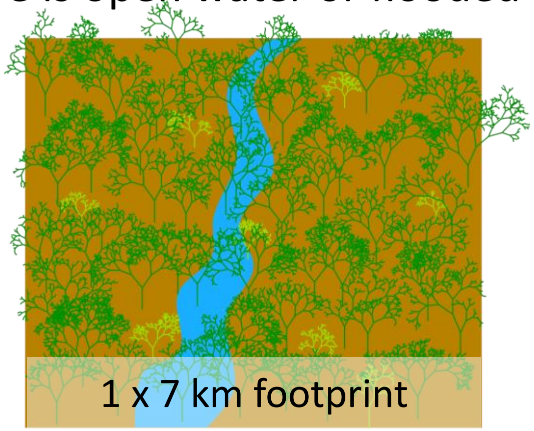
Preliminary Classification

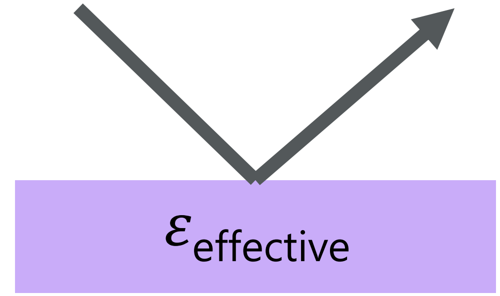
Model: Assumes that the vegetation is dense enough that forward scattering only occurs when there is open water or flooded vegetation.



- Calculates a weighted effective dielectric constant for the scene:

$$\varepsilon_{effective} = (F_W\sqrt{\varepsilon_W} + F_{NW}\sqrt{\varepsilon_{NW}})^2$$

F_W = Areal fraction of open water or flooded vegetation
F_{NW} = Areal fraction that is not open water or flooded vegetation ($F_W + F_{NW} = 1$)
ε_W = Dielectric constant of water (78.9 – 4.3i)
ε_{NW} = Dielectric constant of a medium producing no reflectivity (1.0)



$$\Gamma \propto SNR$$

$$\Delta\Gamma \propto \Delta SNR$$

- $\mathbf{\Gamma}$ calculated from $\varepsilon_{\text{effective}}$

Assumes that a) vegetation caused attenuation is negligible and b) vegetation covered or open dry land does not contribute

Can be generalized to layered media using equations and methodology in *Fuks and Voronovich, 2000,* and *Zavorotny et al, 2010.*

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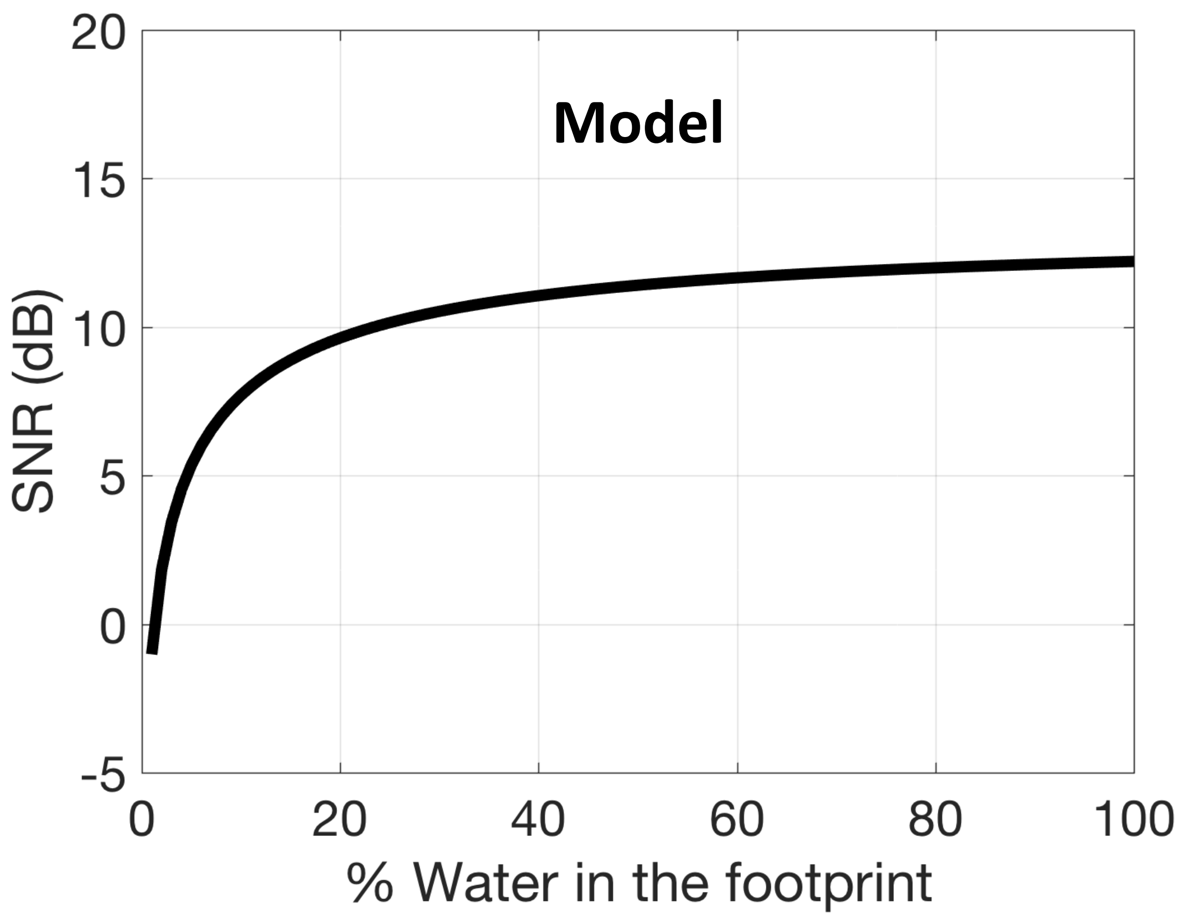
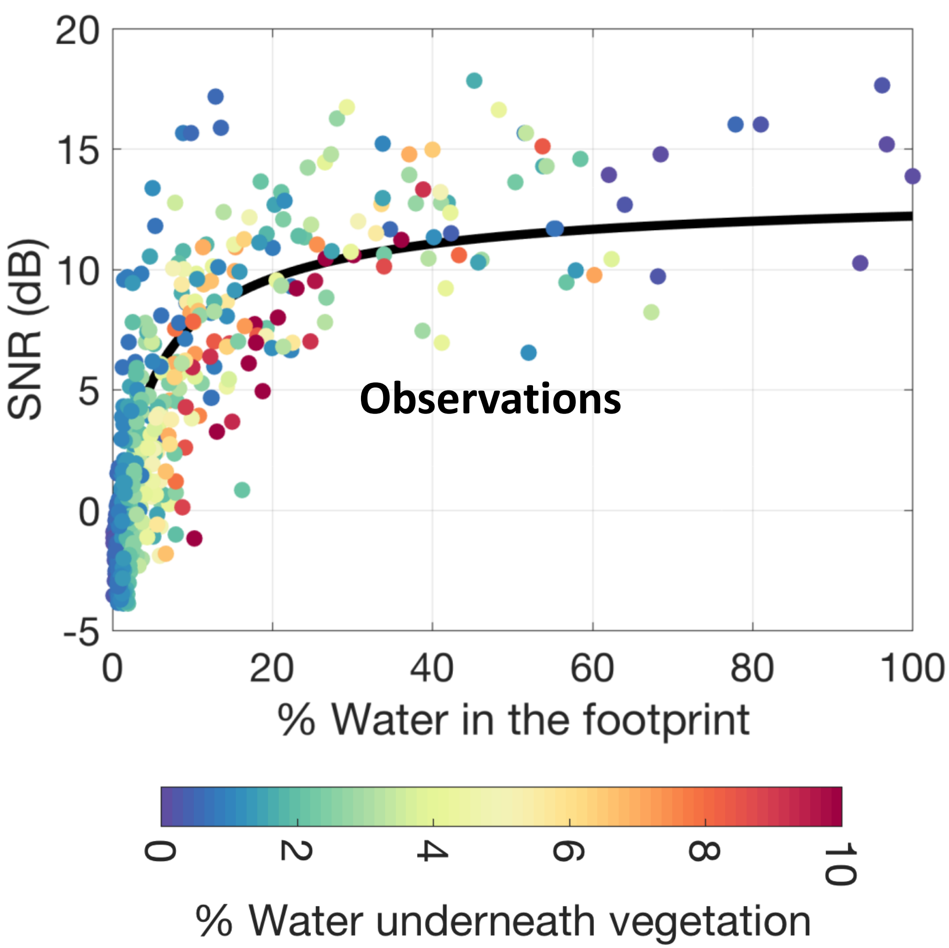


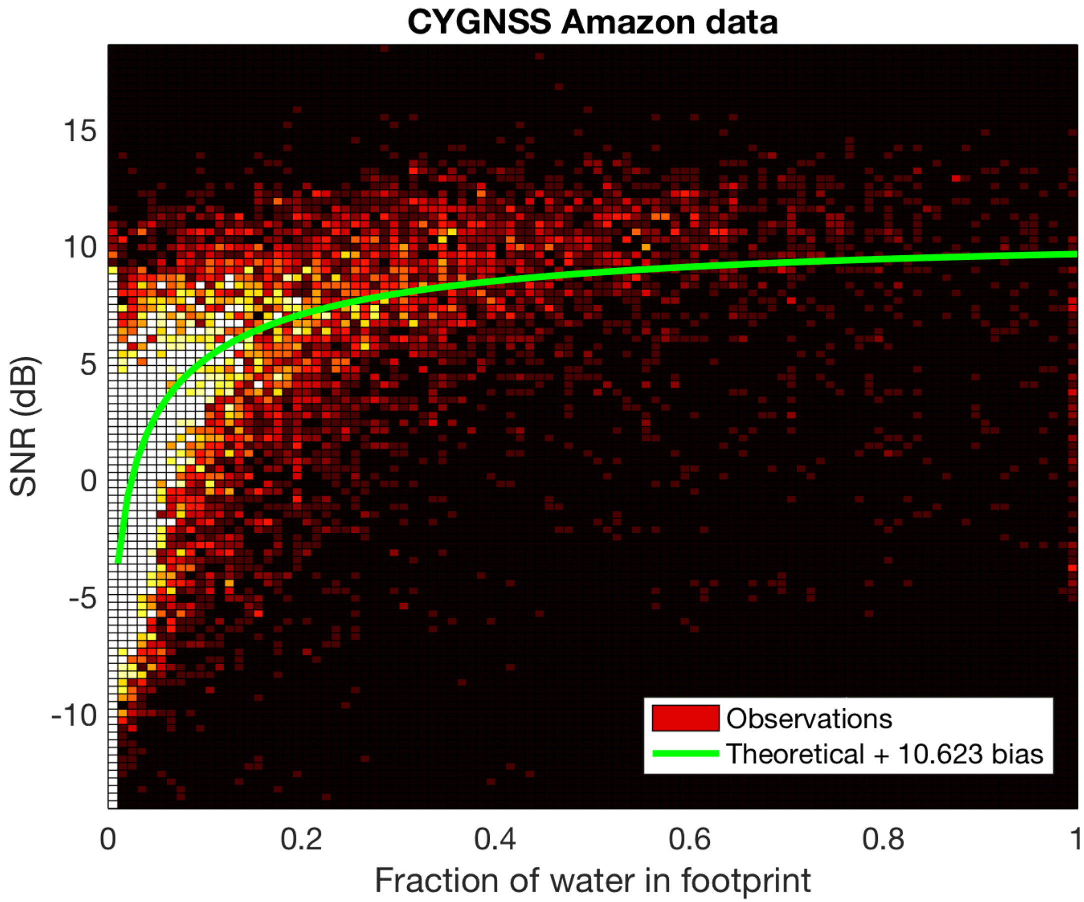
Because the model only simulates changes in SNR, an empirically determined system dependent bias must be removed

Preliminary Classification: TDS-1



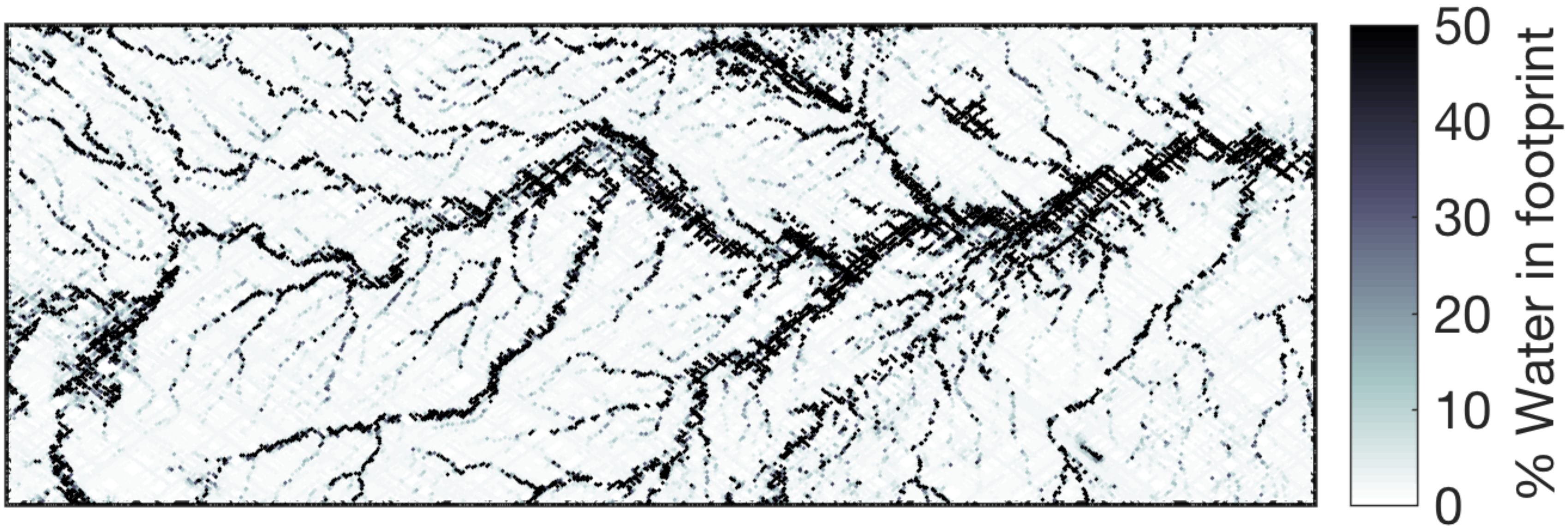
- Assumes a footprint of 1 x 7 km for TDS-1
- Model assumes that the only source of reflectivity in the footprint is surface water.
- Observations are from TDS-1 in the Amazon, those that are contemporaneous with 25-m PALSASR-2 data from 2016 campaign
- The % of water in the footprint of the TDS-1 measurements was estimated with use of PALSAR-2 data.

Preliminary Classification: CYGNSS



- Assumes a footprint of 1 x 7 km for CYGNSS
- Here, we estimated the fraction of water within the CYGNSS footprint using the MODIS 30 m water mask
- Simple model is still applied, corrected for CYGNSS dependent bias

Preliminary Inundation Map



- With the preliminary GMF, we analyzed CYGNSS data over the Amazon region over the period mid-Feb to mid-May, 2017
- Used data from MODIS water mask as truth to classify scene
- Generated example of “inundation map” product

Summary and Next Steps

- GNSS-R observations of wetlands from space have become available, showing an excellent sensitivity with high dynamic range of the peak reflected power
- Wetlands obstructed by vegetation can be detected in general
- Using conventional radar data as a starting point to classify Amazonian wetland types, and mapping the classification to the SNR distribution of coincident TDS-1 and CYGNSS reflections, a promising approach and a preliminary inundation product have been shown
- More extensive validation of the datasets against ground truth is needed to formulate a GMF
- Modeling of the attenuation of the GNSS-R signal over vegetated wetlands is needed to better understand the limitations of this technique